SCALE/TSUNAMI Assessment of Postulated Critical Experiments for Testing of Neutron Cross Sections for Cr, Mo, and Mn

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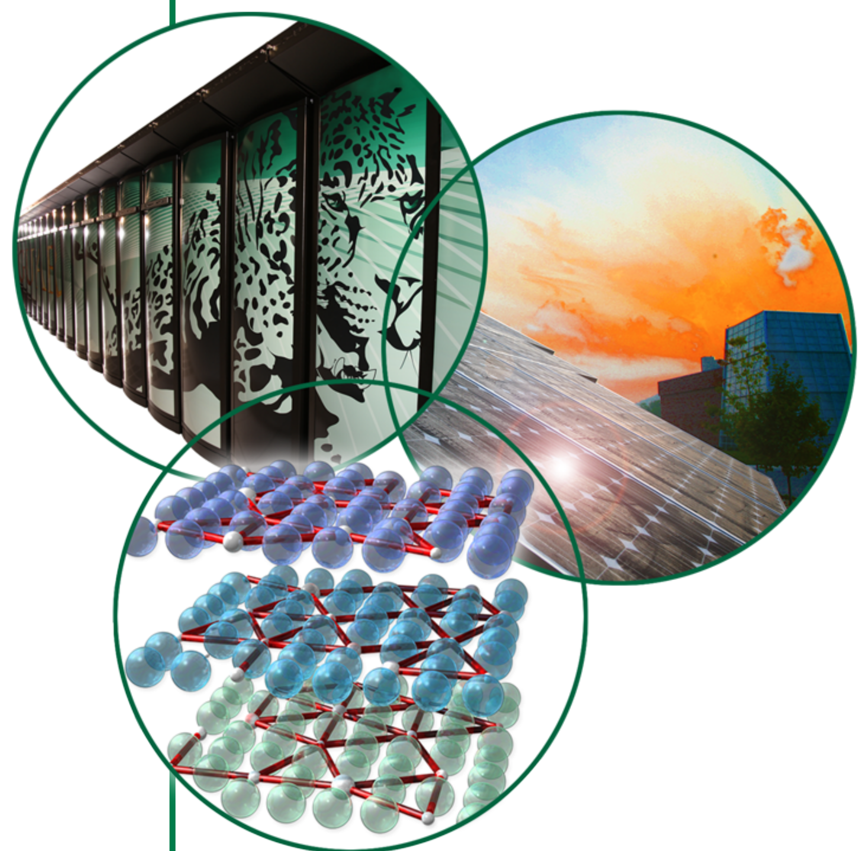

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OAK RIDGE NATIONAL LABORATORY

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Overview

- Objective
- Work product
- Overview of MIRTE* Phases 1 and 2
- Preliminary considerations
- Evaluated configurations
- Results
- Conclusions

* Matériaux en Interaction et Réflexion Toutes Epaisseurs – a critical experiment program at Valduc (France). The program is managed by IRSN (Institut de Radioprotection et de Sûreté Nucléaire). The purpose is to investigate neutron absorption and reflector effects of selected structural materials or components.

Objective

- **Evaluate the feasibility of performing critical experiments for testing of Cr, Mo, and Mn cross sections, with focus on epithermal and fast energy regions.**
- **Provide conceptual configurations for use by MIRTE Phase 2 experiment designers.**

Although specific experiment design is not performed, consideration is given to these design issues:

- control of uncertainties in benchmark-model k_{eff} values, and
- test material availability and compatibility.

Work Product

- Work requested by NCSP management in Feb 2010.
- Letter report* provided in May 2010.
- NCSP management provided the report to IRSN for consideration in MIRTE Phase 2 design.

* Not published

DESIGN OF THERMAL-SYSTEM CRITICAL EXPERIMENTS
FOR TESTING OF FAST- AND EPITHERMAL-NEUTRON CROSS
SECTIONS FOR CHROMIUM, MOLYBDENUM, AND MANGANESE

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Overview of MIRTE Phases 1 and 2

- DOE is collaborating with France (IRSN) in the "MIRTE" experimental program at Valduc.
- MIRTE Phase 1 (Dec 2008 to Jun 2010) examined the following materials as neutron reflectors and absorbers for LEU rod lattices in water: Fe, Ni, Cu, Al, Zr, Pb, Ti, glass (SiO_2) and concrete (various H_2O contents).
- MIRTE Phase 2 is to commence in 2011 and will consider additional materials.

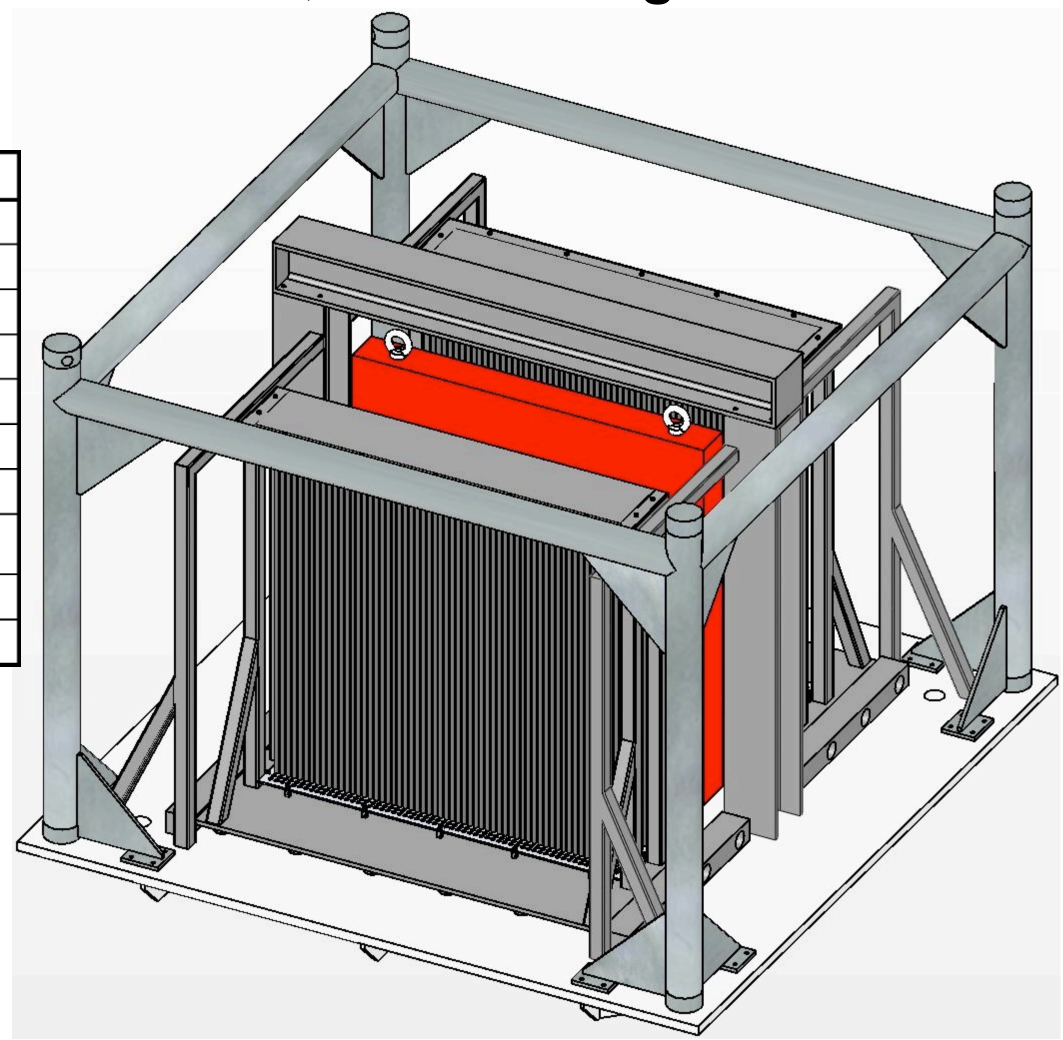
Overview of MIRTE (Continued)

- Fuel: UO_2 rods at 4.7 weight % ^{235}U enrichment, Zircalloy-4 cladding, 0.79 cm pellet diameter. Note: A maximum of 1260 rods are available.
- The fuel rods are well-characterized. Non-MIRTE experiments using this fuel are documented in the IHECSBE (LEU-COMP-THERM-071, -072 and -073).
- Most experimental results of the MIRTE program are proprietary.
- All source information presented here regarding the MIRTE program is publically available (ICSBEP, NCSD 2009 Conference, or the MIRTE Program web page at http://cristal.irsn.org/cristal/mirte).

MIRTE 1 Configurations

- **2-Array (large plate of test material, with oblong lattices on either side)**

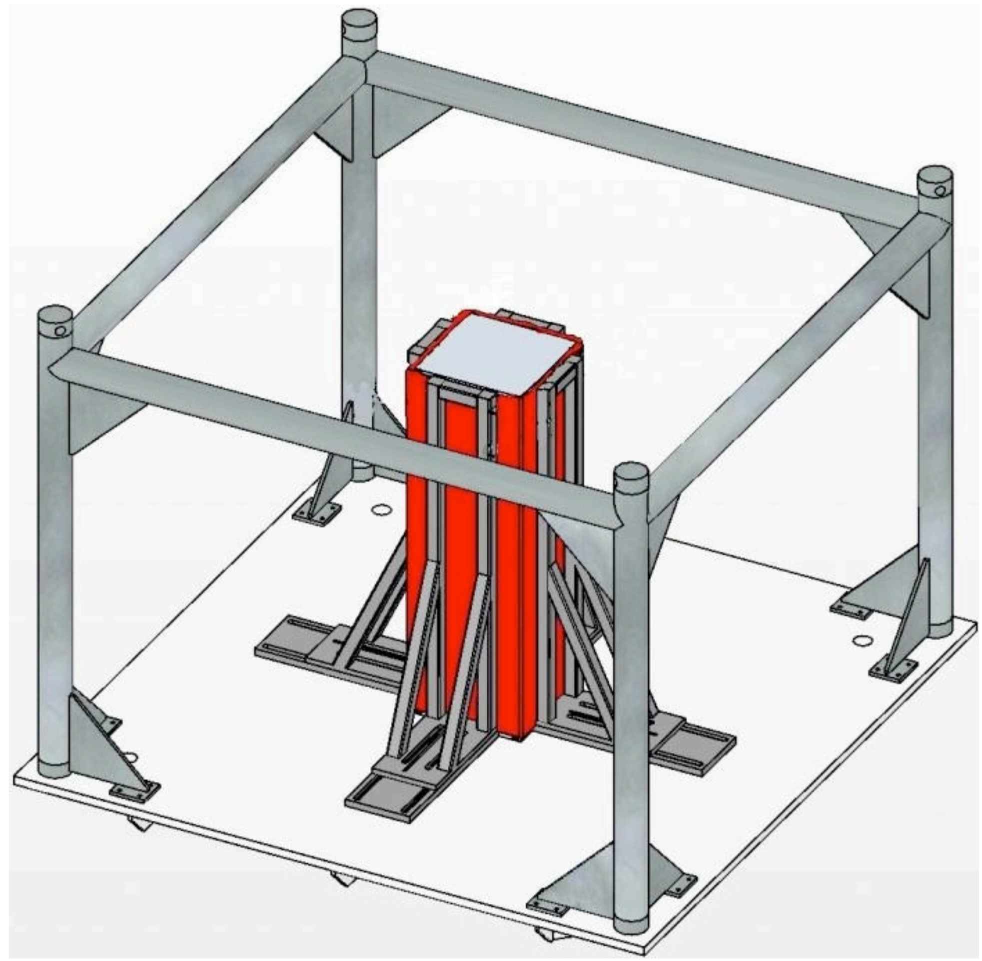
Material	Thickness (mm)
Iron	200
Nickel	200
Copper	50
Aluminium	300
Zircalloy	100
Lead	50
	200
Concrete with about 3 % water content	300
Concrete with about 6 % water content	300
Concrete with about 9 % water content	300



MIRTE 1 Configurations

- **1-Array-Reflected (square lattice reflected on four sides by test material)**

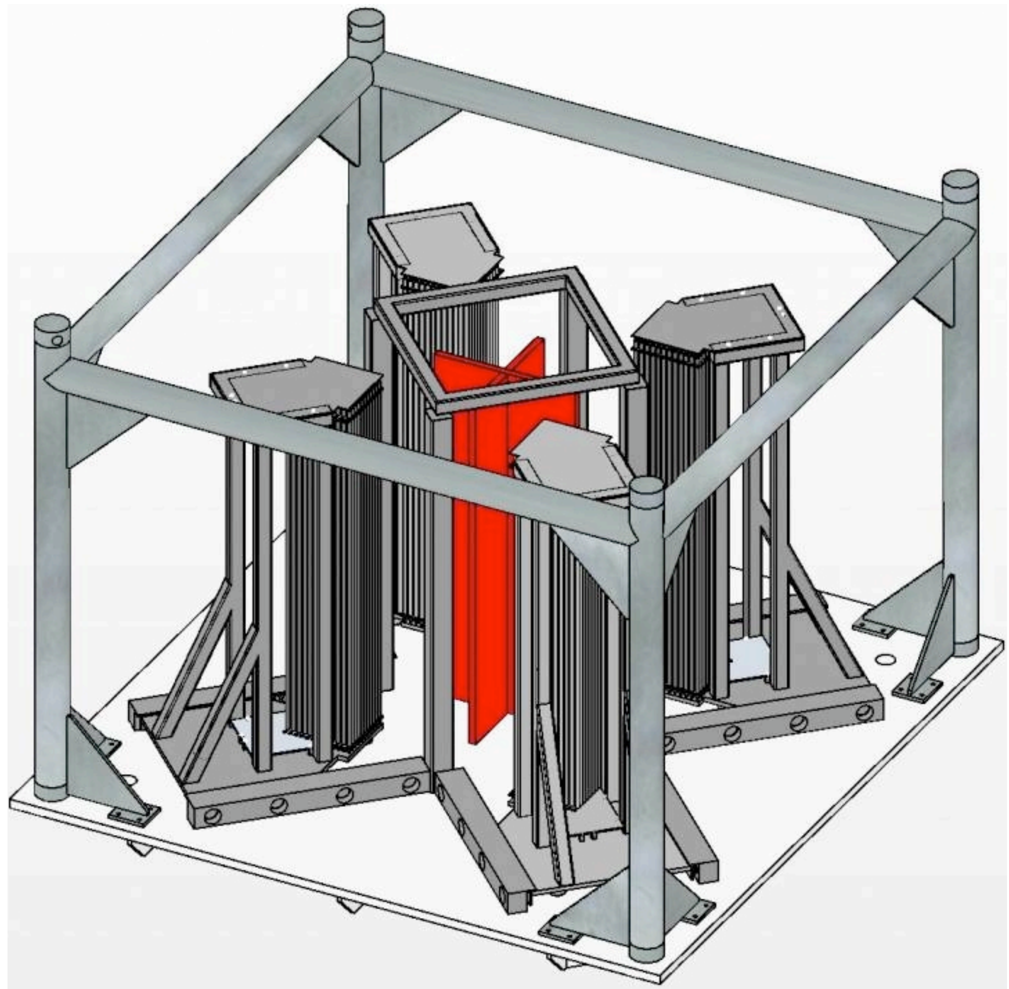
Material	Thickness (mm)
Aluminium	50
	200
Glass (SiO_2)	200



MIRTE 1 Configurations

- **4-Array (cruciform of test material separating four lattices)**

Material	Thickness (mm)
Iron	3
	20
Nickel	3
Copper	5



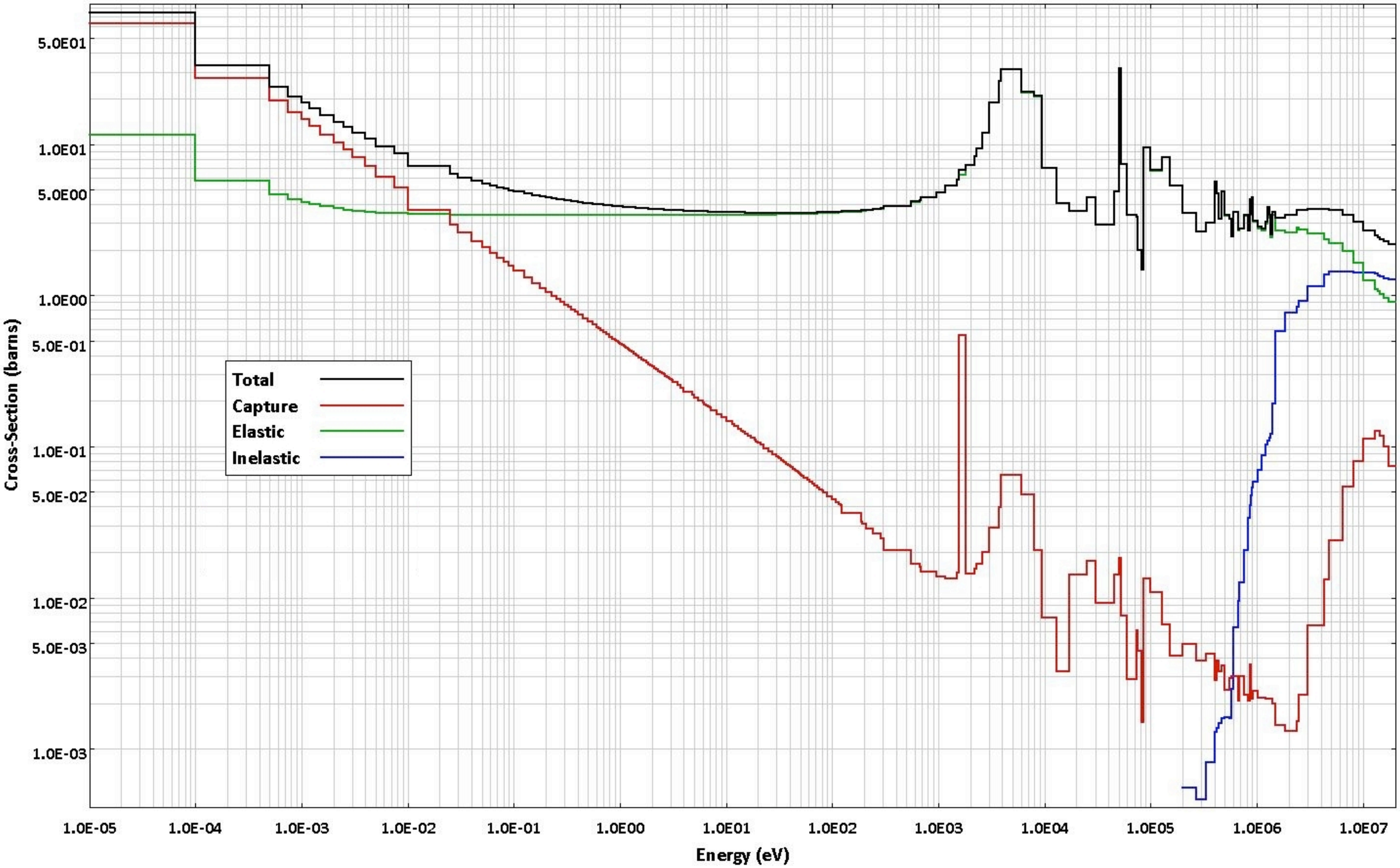
Preliminary Considerations

- **Material availability and compatibility**
- **Cross sections for elemental Cr, Mo, and Mn**
  (SCALE ENDF/B-VII data in 238-group format)
- **Thermal-system utility for testing of epithermal and fast cross sections**
- **TSUNAMI definition of computed k_{eff} sensitivity**

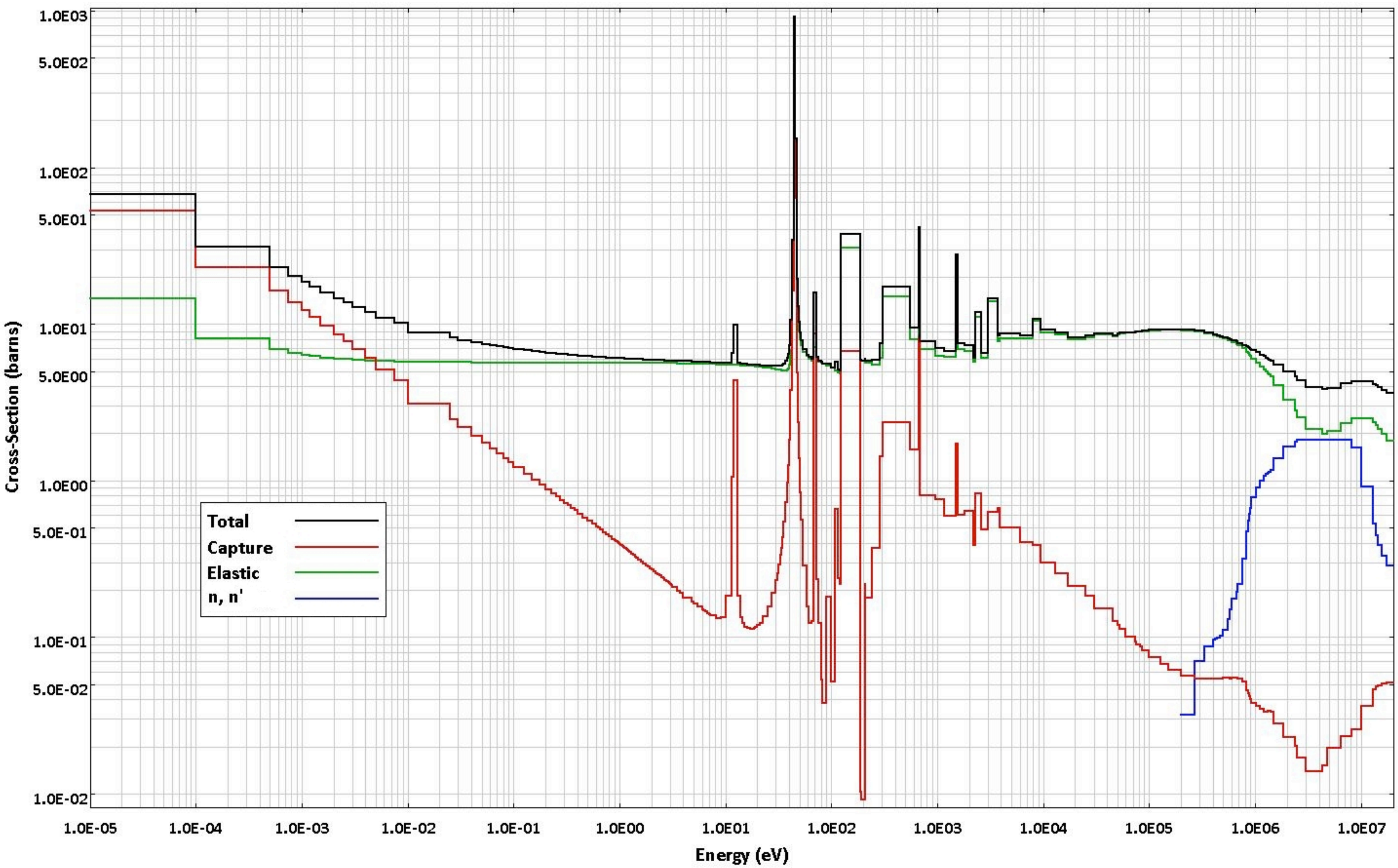
Material Availability/Compatibility

- All three materials are commercially available in metal and oxide forms, at reasonable purities.
- Individual isotopes of Cr and Mo are not available.
- Cr and Mo metals are available in plate, bar, rod, and tube forms. Coatings of Cr metal can be applied by plating.
- Mn metal is available in briquette and ingot forms.
- Mn metal is brittle and slowly reacts with water (evolves hydrogen gas, the resulting oxide is considered toxic).

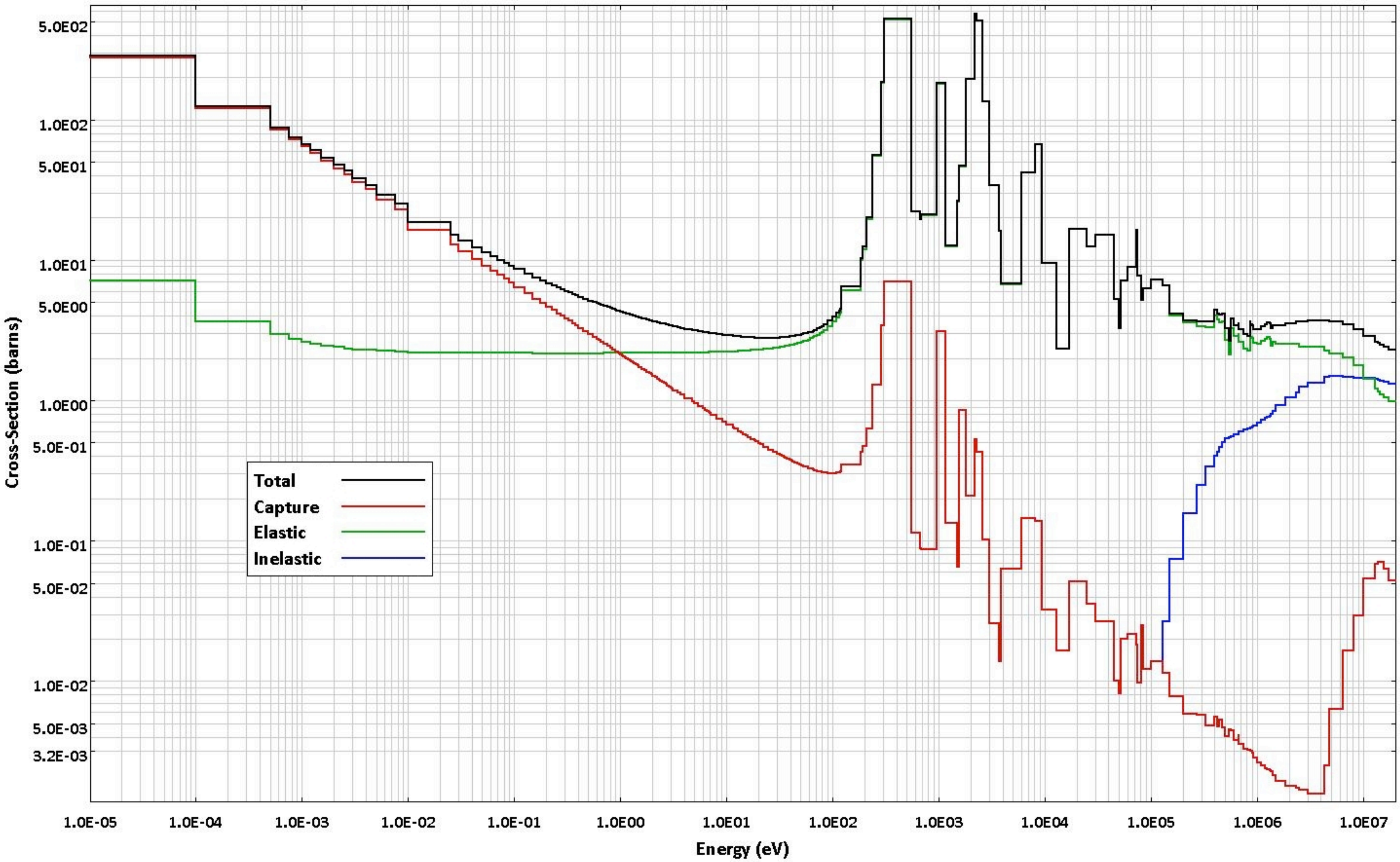
Chromium Cross Sections



Molybdenum Cross Sections



Manganese Cross Sections

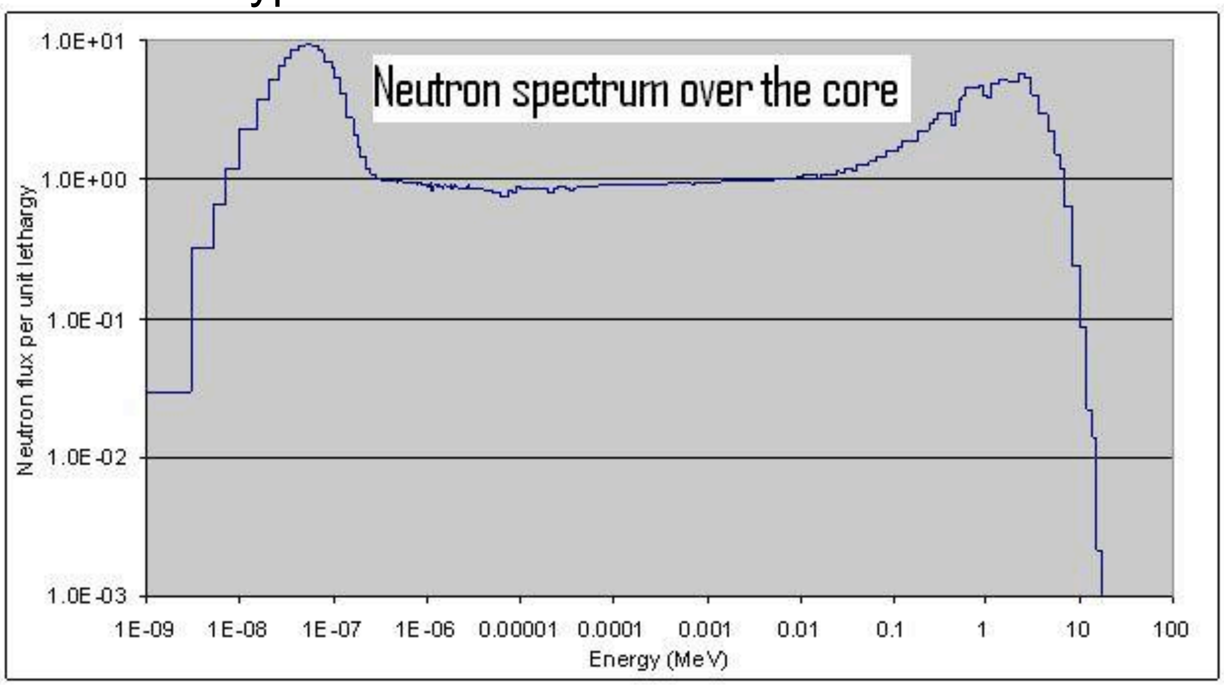


Utility of "Thermal" Systems for Epithermal and Fast Cross Section Testing

- **All neutrons are born fast, and even thermal-fission systems have appreciable epithermal- and fast-neutron fluences.**

Within a MIRTE lattice having a near-optimum rod pitch (1.6 cm), ~ 30% of the neutron flux is epithermal (0.625 eV to 100 keV), and ~ 45% of the neutron flux is fast.

Typical MIRTE Rod Lattice in Water



TSUNAMI Definition of Sensitivity

$$S = (\delta k_{eff}/k_{eff})/(\delta\sigma/\sigma)$$

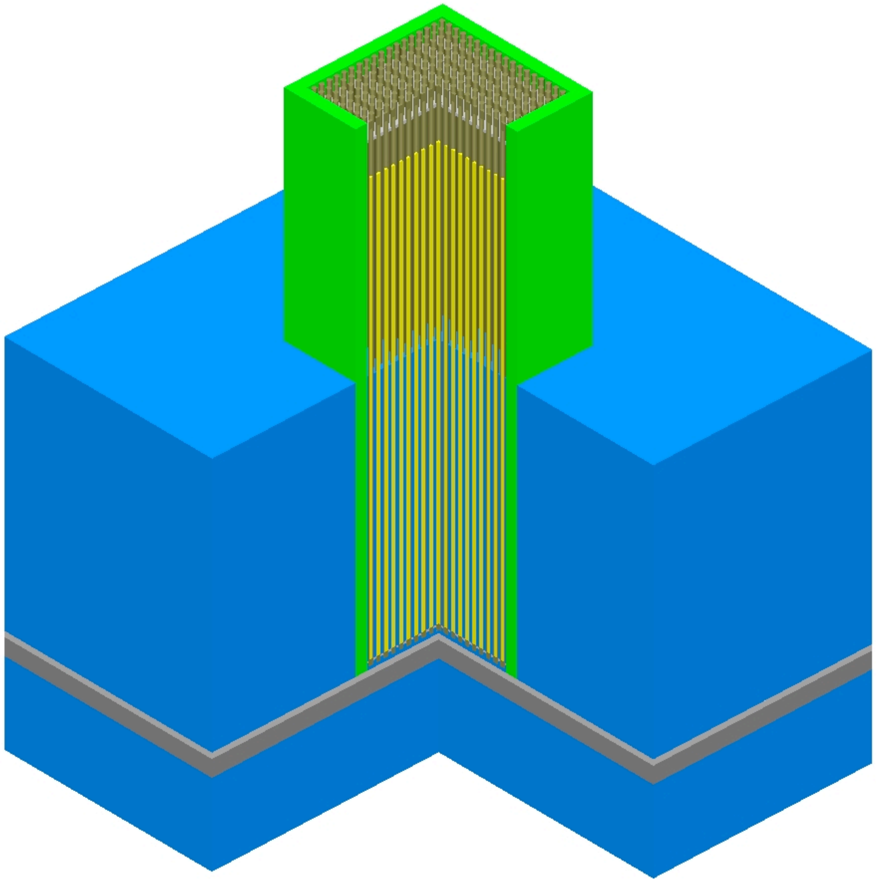
- Sensitivities are determined for each nuclide and nuclide reaction (e.g., $\sigma_{elastic}$, $\sigma_{n-\gamma}$), in each energy group.
- Sensitivities may be integrated over an energy range; sensitivities of constituent isotopes may be summed to give the sensitivity for an element.
- The total sensitivity for a nuclide (or element) is the sum of neutron reaction sensitivities over the full energy range.
- Example: For a nuclide with total S = 0.1, a 10% change in total cross section for the nuclide will result in a 1% change in computed k_{eff}.

Evaluated Configurations

- **1-Array-Reflected**

Test material thicknesses: 3, 6, 12, 25, 50, 100 or 200 mm

Test material form: full-density metal

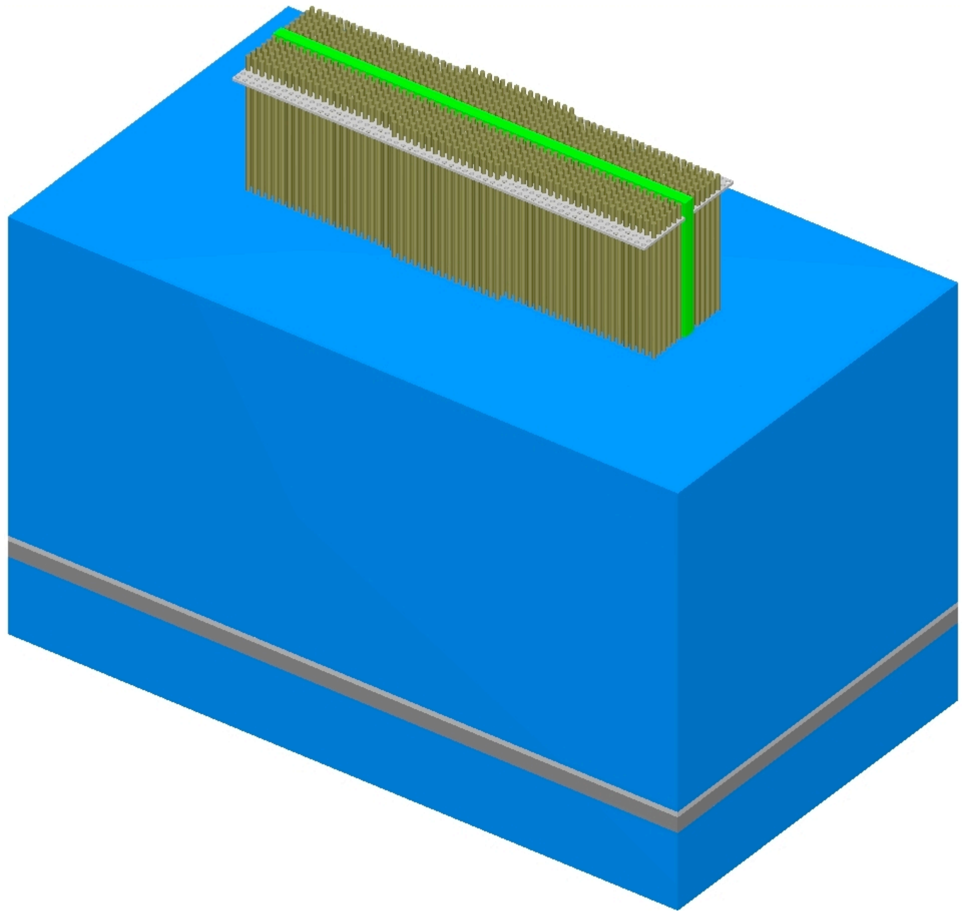


Evaluated Configurations

- **2-Array**

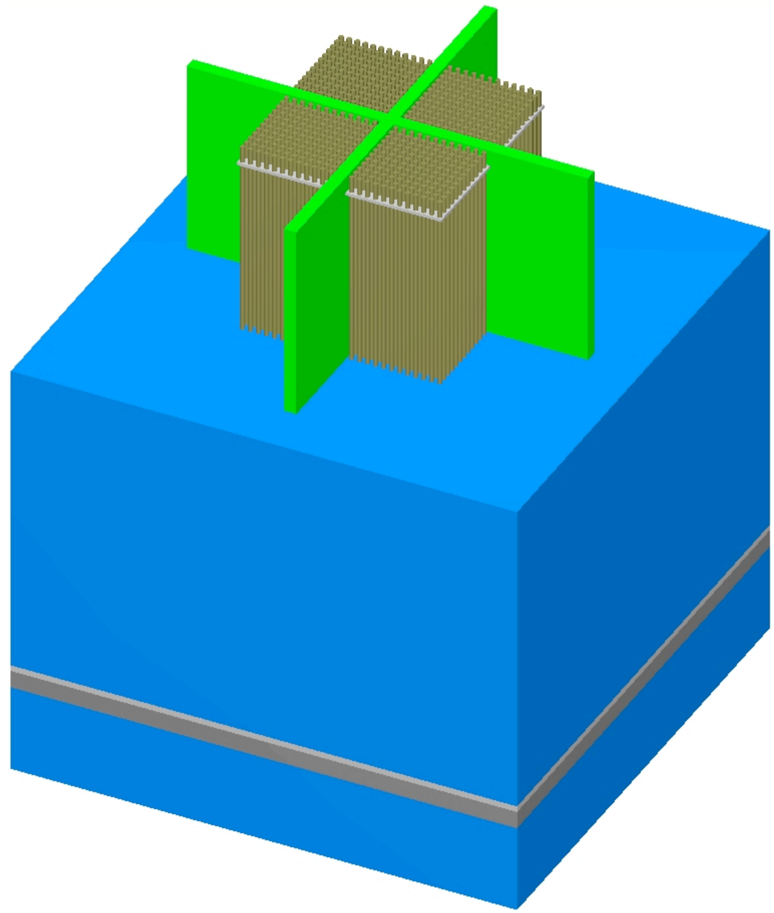
Test material thicknesses: 3, 6, 12, 25, 50, 100 or 200 mm

Test material form: full-density metal



Evaluated Configurations

- **4-Array**



Test material thicknesses: 3, 6, 12, 25, 50, 100 or 200 mm

Test material form: full-density metal

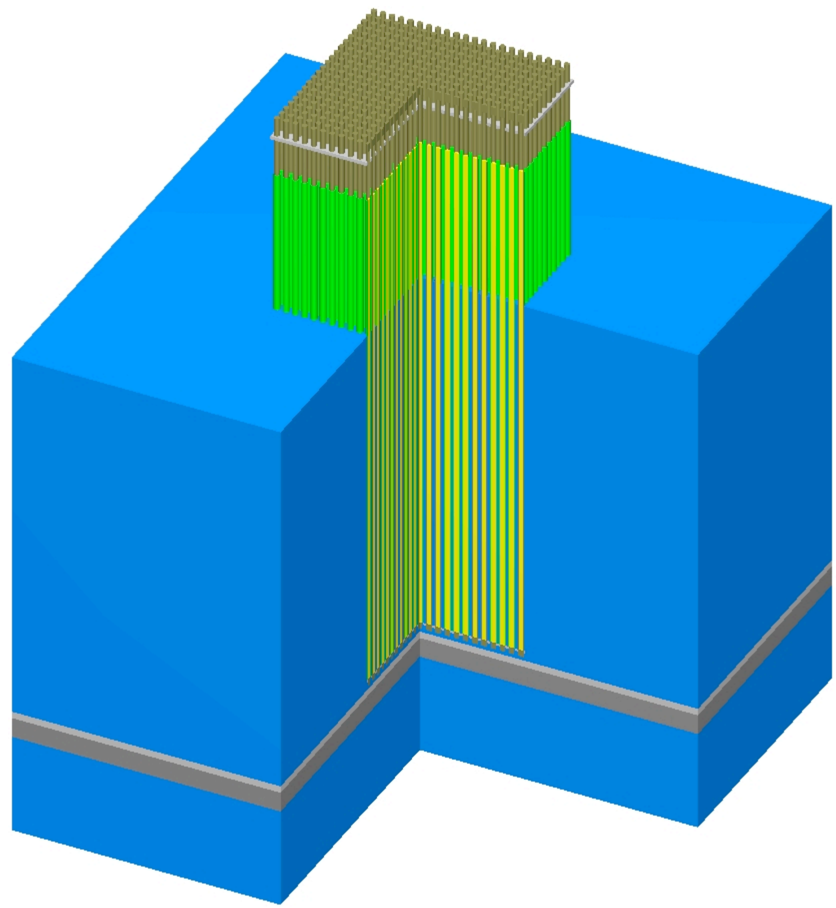
Evaluated Configurations

- **1-Array-Sleeved**
  Test material surrounds each fuel rod as metal plating or as a hollow tube.

  Test material thicknesses: 0.50 and 0.95 mm for Cr and Mo, 0.27 mm for Mn

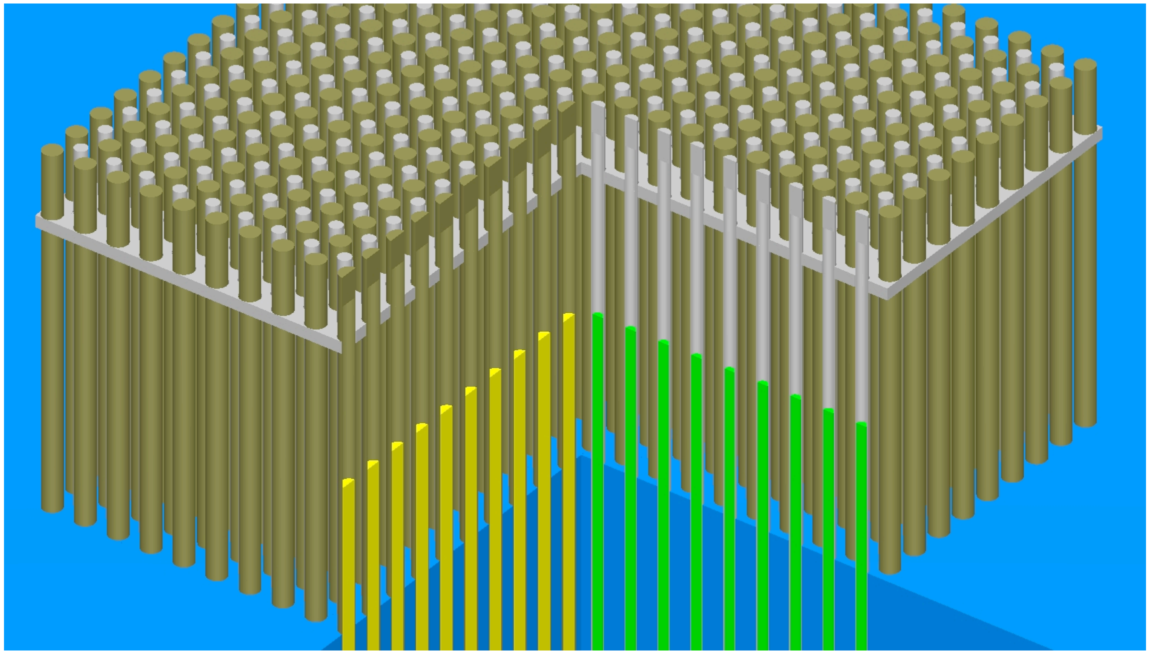
  Test material form: full-density metal

  Good for testing thermal cross sections only



Evaluated Configurations

- **1-Array Poison-Rod**
  Rods of test material are inserted in a checker-board fashion throughout the fuel rod lattice. The fuel rod spacing is increased to 1.7 cm, to maintain the water-to-fuel ratio of a 1.6-cm-pitch array.



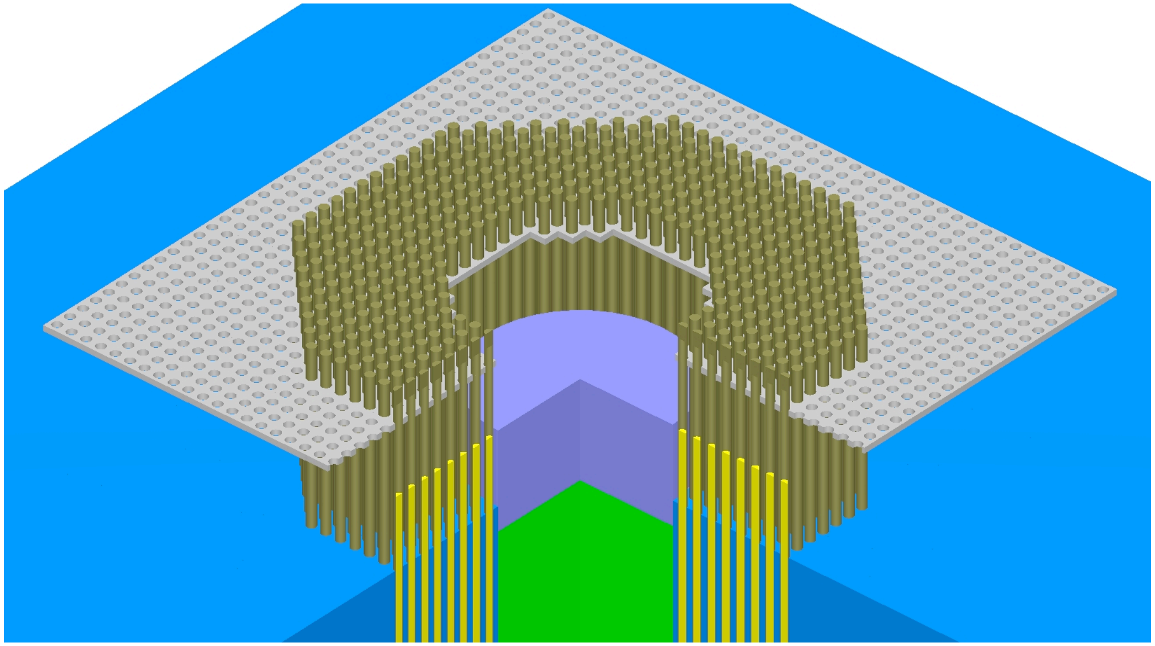
Test material diameter: 0.526 cm, clad in thin-wall aluminum tubes

Test material forms: full-density metal; reduced-density metal (75%, 50%, and 25%) to simulate pressed pellets of metal oxides

Good for testing thermal cross sections only

Evaluated Configurations

- **1-Array Flux-Trap**
  A cylinder of test material is centrally located within a fuel rod lattice.



Test material diameter: 200 mm

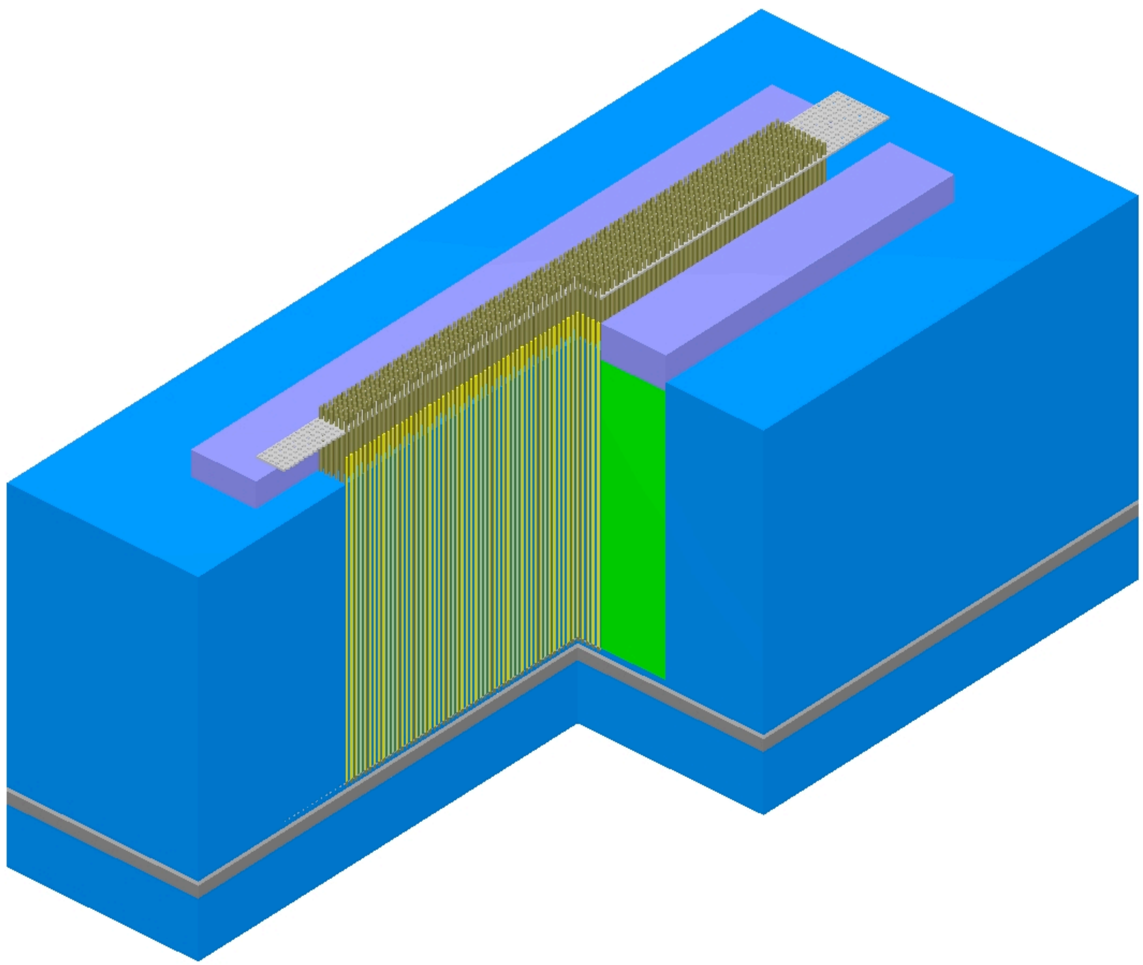
Test material form: full-density metal

Test cylinder is topped by a polyethylene cylinder to reduce vertical neutron leakage.

Good for testing epithermal and fast cross sections only.

Evaluated Configurations

- **1-Array 2-Reflector**
  Two blocks of test material act as reflectors about a central, oblong fuel rod array.

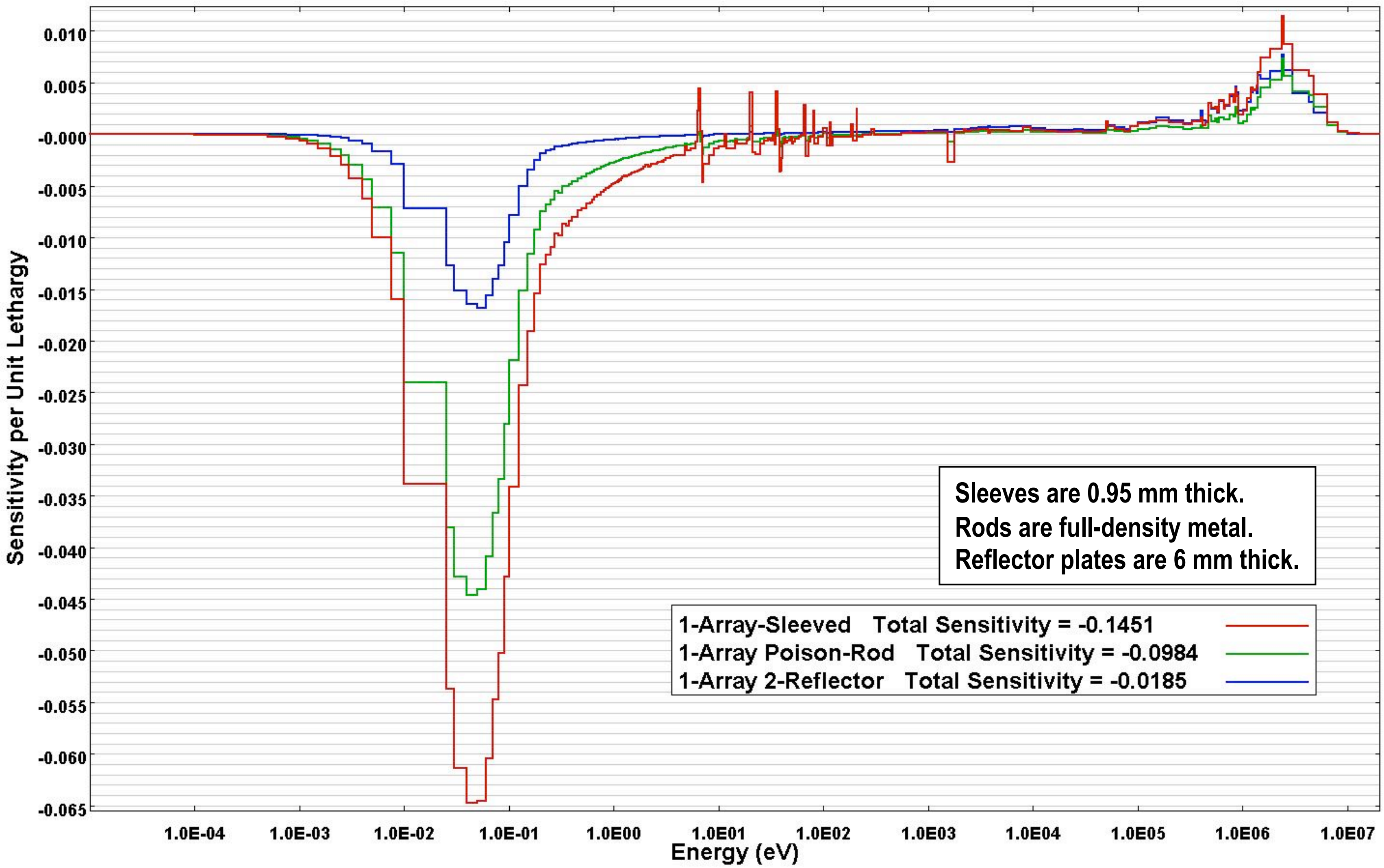


Test material thicknesses: 3, 6, 12, 25, 50, 100 or 200 mm

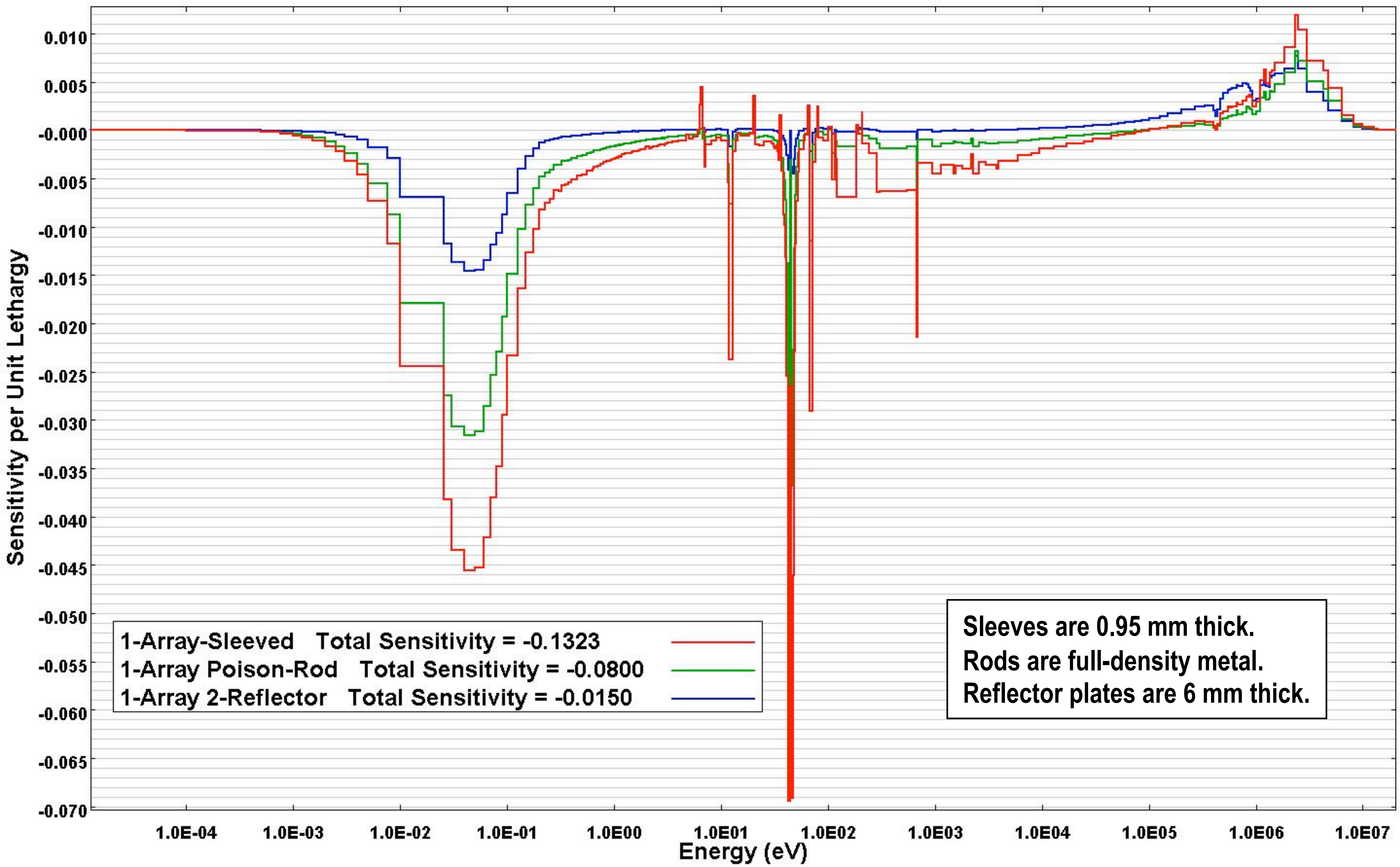
Test material form: full-density metal

Each test block is topped by a polyethylene block to reduce vertical neutron leakage.

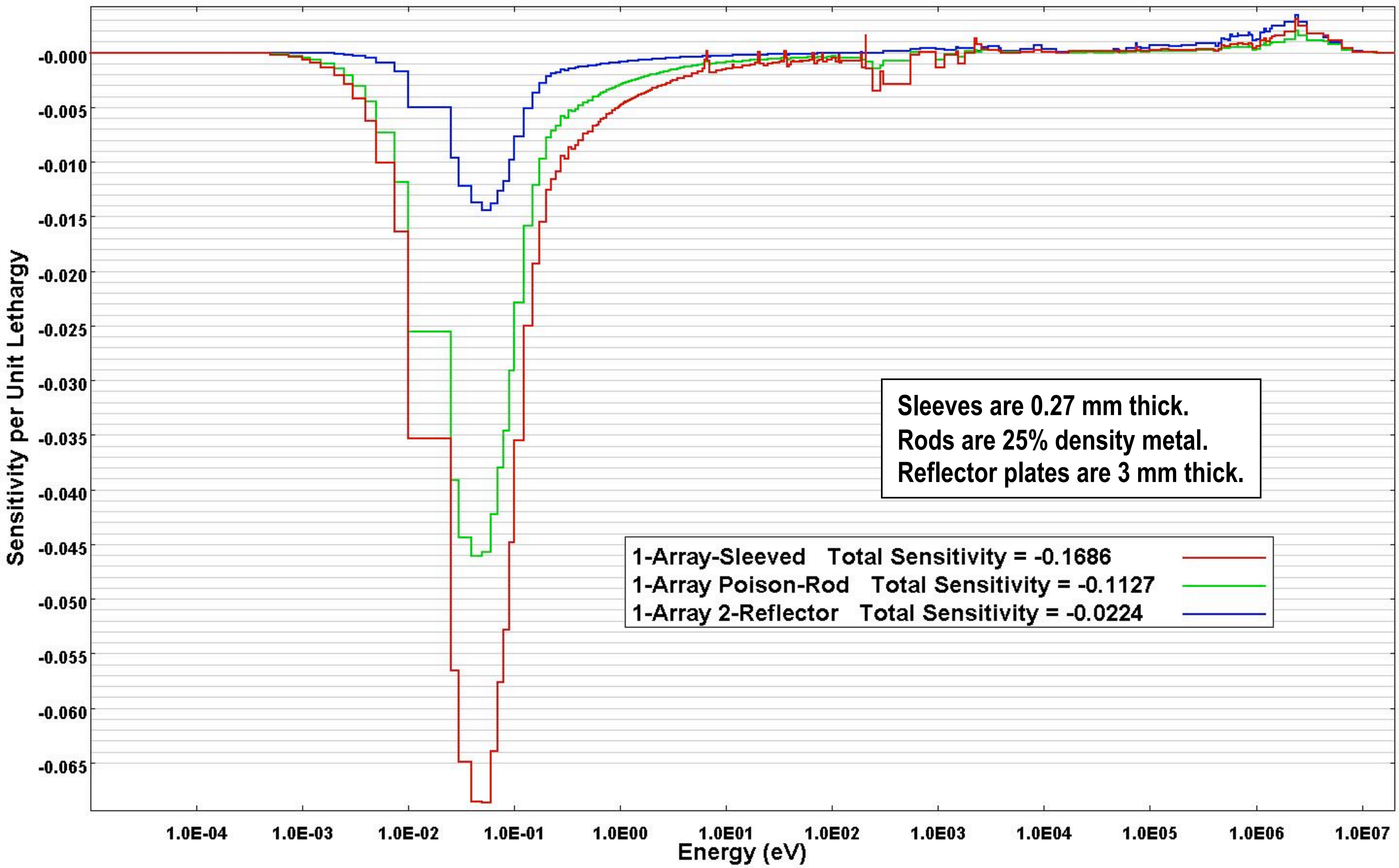
Results - Cr Thermal Testing



Results - Mo Thermal Testing



Results - Mn Thermal Testing



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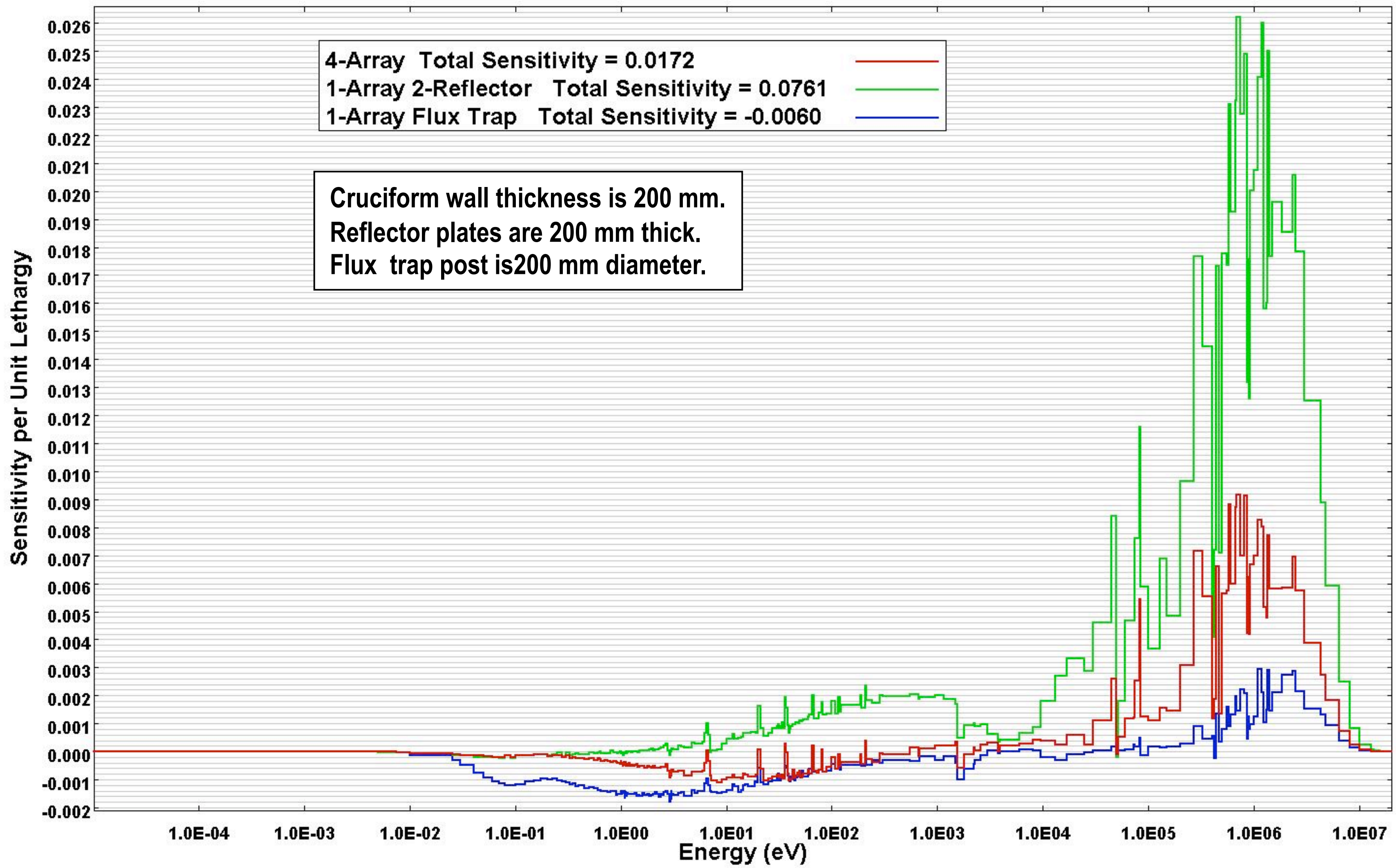
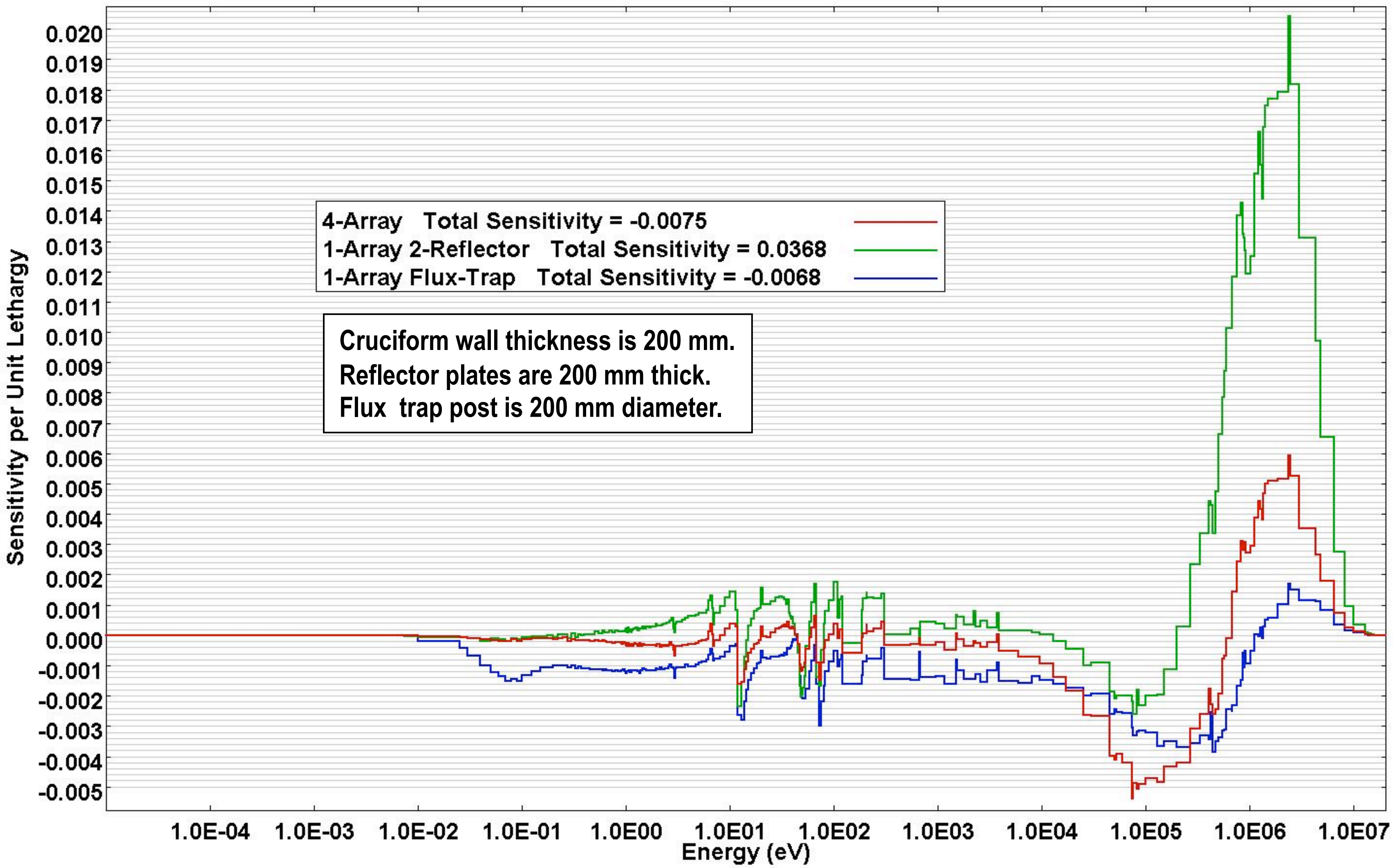
Results - Thermal Testing

- 1-Array 2-Reflector results are approximately the same as the 1-Array-Reflected. (Both configurations have 100% of the lateral surface area of the lattice adjacent to test material.)
- 2-Array sensitivity results are ~ half that of the 1-Array 2-Reflector or the 1-Array-Reflected results. (For the 2-Array configuration, half the lateral surface area of the lattice is not adjacent to test material.)
- For all three test materials, the Poison-Rod configuration presents good thermal sensitivity results without significant epithermal or fast sensitivities.

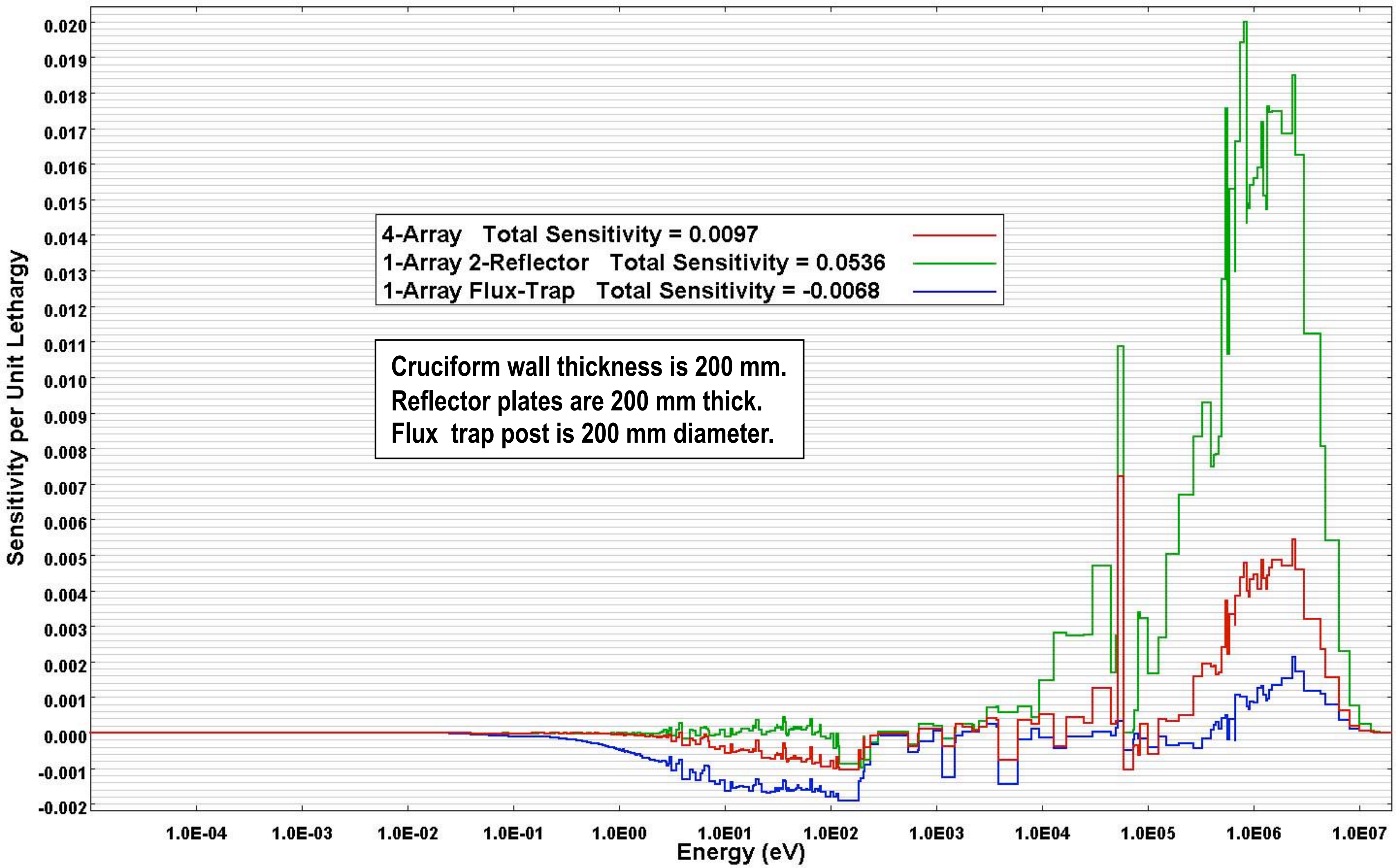
Results - Cr Epithermal/Fast Testing



Results - Mo Epithermal/Fast Testing



Results - Mn Epithermal/Fast Testing



Results – Epithermal/Fast Testing

- 1-Array 2-Reflector results are approximately the same as the 1-Array-Reflected.
- 2-Array sensitivity results are ~ half that of the 1-Array 2-Reflector results.
- For all three test materials, the 1-Array 2-Reflector configuration presents good fast and epithermal sensitivity results with negligible thermal sensitivities.

Conclusions

- The requested feasibility study utilized the SCALE TSUNAMI tools to determine conceptual experiment configurations of utility. Additional details are provided in the report.
- It is possible to employ a thermal-fission system (LEU rod lattice in water) for testing of Cr, Mo, and Mn cross sections throughout neutron energy ranges of interest.
  - For testing of thermal cross sections, the 1-Array Poison-Rod configuration is judged best.
  - For testing of epithermal and fast cross sections, the 1-Array 2-Reflector configuration is judged best.

Conclusions (Continued)

- Given (a) reference lattice experiments with no test materials, (b) experiments that primarily test thermal cross sections, and (c) experiments that test epithermal/ fast cross sections, SCALE TSURFER analysis could
  - Identify potential issues with Cr, Mo and Mn cross sections at specific energy values. This may lead to re-evaluation of existing cross section data or re-measurement of cross section data.
  - Interpret computational results for critical experiments, allowing determination of computational biases in results for process application (safety) models.